CHAPTER

5 Magnetism and Matter

MAGNETISM

Magnetic Field / Magnetic Induction or Flux Density

The total number of magnetic lines of force per unit area due to magnetizing field and due to the field induced in the substance is called flux density (B). The unit in which B is measured is Wb/m^2.

The force experienced by a unit north pole of strength A-m placed at a point in a magnetic field is a measure of the magnetic field intensity

The magnetic field intensity due to a pole of strength m at a distance r and is given by the following expression

$$\overline{B} = \frac{\mu}{4\pi}\frac{m}{r^2}\hat{r} \text{ Wb/m}^2$$

Where μ is the absolute permeability of the medium and is expressed as $\mu = \mu_o \times \mu_r$ where μ_r is relative permeability of the material and μ_o is the permeability of the free space or air and is taken as $4\pi \times 10^{-7}$ Wb/A. m.

Magnetic Field Strength or Magnetizing Field

The magnetic field strength or magnetizing field is given by $\overline{H} = \frac{\overline{B}}{\mu}$ A/m and is independent of the medium.

For a coil having n number of turns per unit length and i_o as the (true) current in the winding, then $H = ni_o$. This value of H is independent of the core material.

Intensity of Magnetization (I or J)

The measure of the magnetization of a magnetized specimen is called intensity of magnetization. It is defined as the magnetic moment per unit volume.

$$\text{Thus, } I = \frac{\text{magnetic moment}}{\text{volume}}$$

As normally the specimen is small its magnetization can be supposed to be uniform. If the specimen is of uniform cross-section a, magnetic length $2l$, and pole strength is m, then $M = m \times 2l$ and $V = a \times 2l$.

$$\therefore I = \frac{m \times 2l}{a \times 2l} = \frac{m}{a} \text{ Wb/m}^2$$

Thus intensity of magnetization is given as pole strength per unit area developed. Its unit is ampere/meter, i.e, A/m.

Magnetic Susceptibility

The magnetic susceptibility (χ) of a specimen measures the ease with which the specimen can be magnetized and can be defined as the ratio of the intensity of magnetization induced in it and the magnetizing field i.e. $\chi = \frac{I}{H}$

Magnetic Permeability

When a magnetic material is placed in a magnetic field, it acquires magnetism due to induction. The lines of force of the magnetizing field concentrate inside the material and it results in the magnetizing of the material. The measure of the degree to which the lines of force can penetrate or permeate the medium is called absolute permeability of the medium and denoted by μ. The permeability is defined as the ratio of the magnetic induction B in the medium to the magnetizing field H i.e. $\mu_a = \mu_o\mu_r = B/H$

When a magnetic material of cross-sectional area A and relative permeability μ_r is placed in a uniform field H, two types of lines of induction pass through it, one due to the magnetizing field H and the other due to the material itself being magnetized by induction. Thus, the total flux density B will be given by

$$B = \mu_o H + \mu_o I$$

As $\mu = \mu_o\mu_r = B/H$

$$\therefore \quad \frac{B}{H} = \frac{\mu_0 H + \mu_0 I}{H} = \mu_0 + \frac{\mu_0 I}{H} = \mu_0 [1 + \chi]$$

$$\mu_r = 1 + \chi \text{ or } \frac{\mu}{\mu_0} = 1 + \chi$$

PARA, DIA, FERRO-MAGNETIC SUBSTANCES

Magnetic substances are substances which upon being introduced into an external magnetic field magnetize so that they themselves become source of an additional magnetic field. Based on their magnetic behaviour, substances can be classified into the following three categories.

Paramagnetic Substances

The substances which when placed in a magnetic field acquires a weak magnetization in the same direction as the applied field are called paramagnetic substances. The examples are platinum, aluminium, manganese, chromium, copper sulphate, iron or nickel salt solutions and crown glass. Their properties can be summarized as

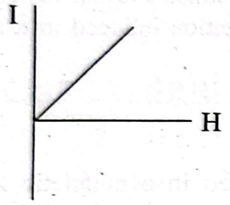
(i) These substances in non-uniform magnetic field, experience an attractive force towards the stronger part of the field.

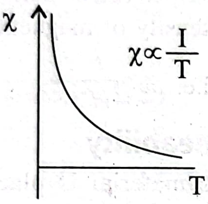
(ii) The relative permeability μ_r for a paramagnetic substance is slightly greater than one

(iii) The magnetic susceptibility is small positive value

(iv) For a given temperature χ does not change with variation in H.

(v) The susceptibility varies inversely as the absolute temperature and at very high temperature its value becomes negative.





Slope = χ

Diamagnetic Substances

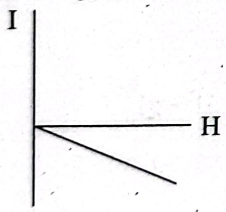
The substances, which when placed in a magnetic field acquire weak magnetization in a direction opposite to that of the applied field are called diamagnetic substances. The examples are bismuth, antimony, water, alcohol and hydrogen. These substances exhibit the following properties.

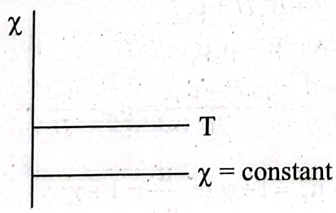
(i) These substances are repelled by strong magnetic field.

(ii) The relative permeability μ_r for diamagnetic substance is less than one but positive.

(iii) Susceptibility for diamagnetic has a small negative value. This value does not vary with field or temperature.

(iv) A diamagnetic substance reduces the flux density B.





Slope = χ

Ferromagnetic Substance

Such substances acquire high degree of magnetization in the same sense as the applied magnetic field. The example are: iron, steel, nickel and cobalt. Ferromagnetic substances exhibit the following properties:

(i) They have relative permeability of the order of hundreds and thousands.

(ii) Susceptibility is also very large and positive.

(iii) For small values of H susceptibility remains constant and for moderate value of H increases rapidly with H and for large value attains a constant value.

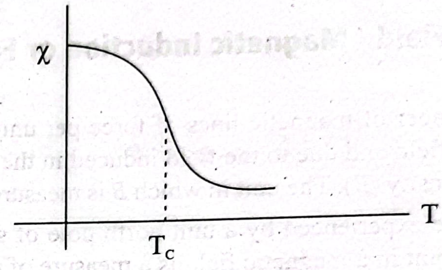
(iv) They are attracted even by weak magnet.

(v) As temperature increases the value of χ decreases. Above certain temperature ferromagnetic material become ordinary paramagnetic material and this temperature is called Curie temperature. For iron, steel and nickel the curie point is 1000°C, 770°C and 360°C respectively.

The susceptibility is given by $\chi = \dfrac{C}{T - T_c}$ [for $T > T_C$]

where C is called Curie constant

This is also called as Curie Weiss law.

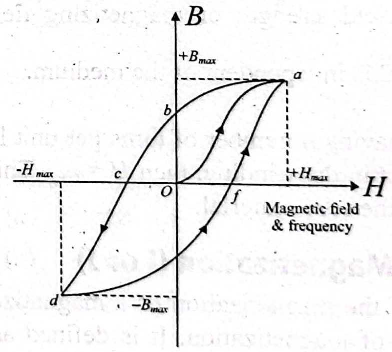


(T_c = Curie Temperature)

HYSTERESIS

Hysteresis Loop

If we take a ferromagnetic material in completely demagnetized state and make it to undergo a cycle of magnetization in which H is increased from zero to a maximum value H_{max}, then decreases to zero, then reversed and taken to $-H_{max}$, and finally brought back to zero. The variation of B with respect to H can be represented by a closed Hysteresis loop as shown in figure.



To get this graph measure B and H and plot these values. Increase H from zero to H_{max} and draw the curve oa (the maximum value is known as saturation value), this is the normal magnetization curve. Now decrease H from H_{max} to zero. B will not fall as rapidly as it increased and will fall back to b rather than zero giving ab as the back trace of oa. Therefore, even when the magnetizing force is made zero or removed, the iron is still magnetic and the flux density ob is called residual magnetism or **retentivity**. Now, reverse the magnetizing field H. The value of B becomes zero at point c at

which the substance is no longer a magnet. Now, H is increased to $-H_{max}$ and graph cd is obtained. Change $-H_{max}$ to zero and then to H_{max} again curve dfa is obtained. This lagging of the B with respect to the magnetizing force H is called **hysteresis** and the close loop graph is known as hysteresis loop. The value of H required to destroy the residual magnetism is called the **coercivity** which is represented by oc.

Energy Loss Due to Hysteresis

To produce a magnetic field a certain amount of energy has to be supplied. This energy is stored in free space where field is established and is returned to circuit when field collapses.

However in case of ferromagnetic substances not all the energy supplied can be returned; part of it is lost in form of heat etc. If the magnetization is carried through a complete cycle, the energy lost is proportional to the area of the hysteresis loop.

When a magnetic material is taken round cycle, there is an energy loss per unit volume of the material given by the area enclosed by B–H curve.

Properties of Soft and Hard Materials

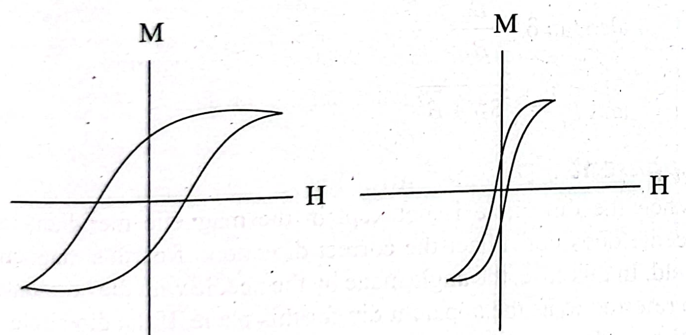
The shape of the B–H curve depends upon the ferromagnetic substance as shown in figure i.e. it is the characteristic of the substance. From the following figures it can be concluded that

(i) The susceptibility is more for soft materials than for hard material.

(ii) Permeability is more for soft materials than for hard materials.

(iii) Soft materials have low retentivity and low coercivity as compared to hard materials.

(iv) Hysteresis loss for soft materials is less than that of hard materials.



Steel　　　Soft iron

Train Your Brain

Example 1: Which of the following is suitable for the core of electromagnets

Sol. Soft iron is more suitable for core of an electromagnet because of its low hysteresis area so as to minimize the heat losses in each cycle.

Example 2: Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond curie temperature then it will show

Sol. If temperature of a ferromagnetic substance is increased beyond curie temperature then it starts behaving as a paramagnetic substance.

Example 3 : If a paramagnetic substance is taken closer to north pole or south pole of bar magnet, then it will be

Sol. Paramagnetic substance is attracted by both poles.

Concept Application

1. Which of the following is suitable for making a bar magnet?
   (a) Soft iron
   (b) Steel
   (c) Nickel
   (d) Copper

2. Which property is present in all the substances?
   (a) Ferromagnetism
   (b) Paramagnetism
   (c) Diamagnetism
   (d) Antiferromagnetism

3. A solenoid has 5 turns per centimeter and relative permeability of core is 100. Electric current through insulated winding of the solenoid is 2 mA. The value of magnetic field strength (B) in standard unit is
   (a) 1　　(b) 100
   (c) 1×10^{-2}　　(d) 10

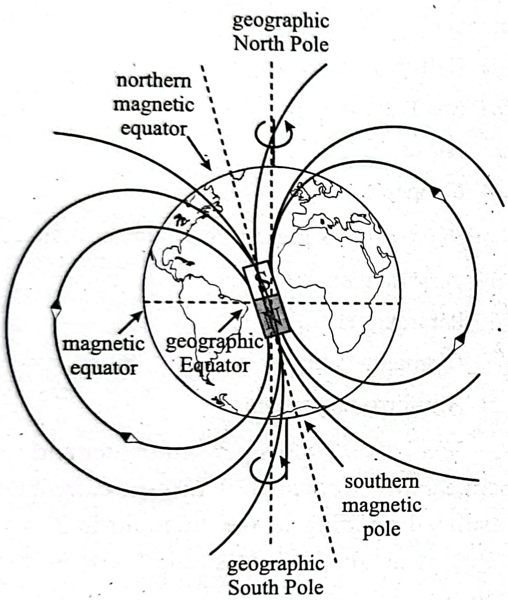
4. If the magnetic susceptibility of a material is 2 and it is placed in a magnetising field H = 2 A/m. Calculate the value of magnetic field inside the material (μ_0= Magnetic permeability of air)
   (a) $2\mu_0$　　(b) $4\mu_0$
   (c) $6\mu_0$　　(d) $5\mu_0$

5. Relative permeability of a material such as book is 3. Then what will be the value of relative magnetic permeability at 600 K.
   (a) 1　　(b) 2
   (c) 3　　(d) 0

6. Curie-Weiss law is obeyed by ferromagnetic material
   (a) At curie temperature
   (b) Below curie temperature
   (c) Above curie temperature
   (d) For all temperatures

EARTH'S MAGNETIC FIELD (TERRESTIAL MAGNETISM)

The fact that a freely suspended magnetic compass needle or a bar magnet orients itself roughly along the geographical North-South axis of the earth indicates that there is a magnetic field around the earth. This field is due to circulating electric currents (motion of charged ions of molten substances inside the earth) deep within its interior. We can visualize this field as due to a fictitious magnetic dipole placed deep inside the earth (See figure). The earth will not behave like a magnet if it stops rotating.



COMPONENTS OF EARTH'S MAGNETIC FIELD

Following are three main components of earth's magnetic field.

Angle of Declination (θ)

A vertical plane passing through N-S line of a freely suspended magnet is called magnetic meridian and the vertical plane passing through the geographical North-South direction is called geographical meridian. The angle of declination is defined at a place as the angle between magnetic meridian and geographical meridian as shown in figure.

Isogonic line: A line on a map which connects the points having same angle of declination.

Agonic line: A line on a map which connects the points having zero angle of declination.

Angle of Dip or Inclination (δ)

The total intensity of earth's magnetic field varies in magnitude as well as in direction from place to place. The angle which the resultant earth's magnetic field makes with the horizontal line in the magnetic meridian is called magnetic dip or inclination. For measuring this angle we use dip circle and at poles $\delta = 90°$ and at equator $\delta = 0$.

Isoclinic Line: A line on a map which connects the points having same angle of dip

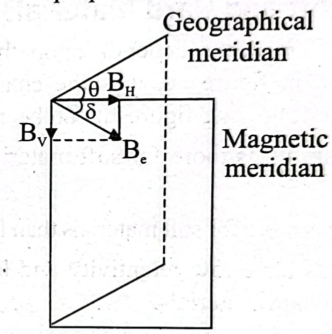
Aclinic Line: A line on a map which connects the points having zero angle of dip. This line is also called magnetic equator.

Horizontal Component and Vertical Component

The resultant magnetic field due to earth 'B_e' can be resolved into two components.

(1) **Horizontal component (B_H):** The component of resultant magnetic field parallel to surface of earth. Line joining points having same horizontal component are called isodynamic lines.

(2) **Vertical component (B_V):** The component of resultant magnetic field perpendicular to the surface of earth.



From above figure,

$B_H = B_e \cos\delta$ and $B_V = B_e \sin\delta$.

also $\tan\delta = \dfrac{B_V}{B_H}$

and $B_e = \sqrt{B_H^2 + B_V^2}$

Apparent dip

When the dip circle is not kept in the magnetic meridian, the needle does not reflect the correct direction of earth's magnetic field. In this case, the angle made by the needle with the horizontal is referred to as the apparent dip for this plane. If the dip circle is at an angle α to the meridian, the effective horizontal component in this plane is

$B'_H = B_H \cos\alpha$. The vertical component is still B_V. If δ' is the apparent dip and δ is the true dip, we have

$$\tan\delta' = \frac{B_V}{B'_H} = \frac{B_V}{B_H\cos\alpha} = \frac{\tan\delta}{\cos\alpha}$$

Neutral Points

When a magnet is placed at some point on earth's surface, there are points where horizontal component of earth's magnetic field is just equal and opposite to the field due to the magnet. Such points are called neutral points. If a magnetic compass is placed at a neutral point, no force acts on it and it may set in any direction.

Train Your Brain

Example 4: The value of angle of dip at poles.

Sol. At poles horizontal component of magnetic field is zero, hence angle of dip is 90°

Example 5: At a place on the surface of earth, where dip angle is 90°, the earth's magnetic field is 3×10^{-7} tesla. There is a long wire carrying 2 A current kept horizontally on ground. The net magnetic field at a distance of 1m vertically above wire is

Sol. Since angle of dip is 90°, direction of earth magnetic field will be perpendicular to surface of earth and magnetic field due to wire will be parallel to surface of earth

Hence, $B_{net} = \sqrt{B_w^2 + B_e^2}$

B_w = magnetic field due to wire

B_e = magnetic field due to earth.

$B_e = 3\times10^{-7}$ T

$B_w = \dfrac{\mu_0 I}{2\pi d} = 4\times10^{-7}$ T

$\Rightarrow B_{net} = 5\times10^{-7}$ T

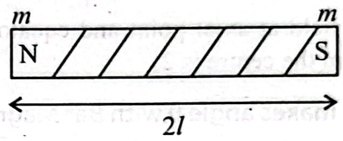
Concept Application

7. A bar magnet is kept on table at a place where dip angle is 90°. The number of neutral points on surface of table is
   (*a*) 2 (*b*) 4
   (*c*) Zero (*d*) Infinite
8. Lines on a map joining points of equal dip angle and equal declination are respectively called as
   (*a*) Isogonic lines, Isoclinic lines
   (*b*) Isoclinic lines, Isogonic lines
   (*c*) Agonic lines, Aclinic lines
   (*d*) Aclinic lines, Agonic lines
9. A compass needle free to rotate in horizontal plane is placed at the centre of circular coil having 100 turns and 3.14 cm radius. The coil lies in a veritcal plane which makes 45° angle with magnetic meridian. If current in coil is $\sqrt{2}$A and the needle points west to east, then horizontal component of earth's magnetic field in gauss is
   (*a*) 10 G (*b*) 15 G
   (*c*) 20 G (*d*) 40 G
10. A pirate ship is sailing towards south east according to the compass. If angle of declination at that place is 45° east of north then actual direction in which ship is sailing
    (*a*) East (*b*) West
    (*c*) North (*d*) South

BAR MAGNET

Introduction: It is a kind of permanent magnet in the shape of rod.

It can be viewed as a magnetic dipole having North and South pole seperated by some distance, as shown in figure.



Magnetic Moment of Bar Magnet $|\vec{M}|$

$|\vec{M}|$ = Pole Strength × distance b/w poles

$\boxed{|\vec{M}| = m\times 2l}$

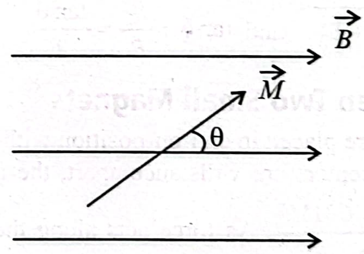
m : strength at each pole

$2l$ = distance b/w two poles.

Direction: South pole to North pole.

Dipole in Uniform Magnetic field, $\vec{B}$

(a) Torque on dipole in uniform magnetic field



$\vec{\tau} = \vec{M}\times\vec{B}$

$|\vec{\tau}| = MB\sin\theta$.

At θ = 0 and θ = 180°, $\vec{\tau} = 0 \Rightarrow$ Equilibrium positions.

(b) Potential energy of dipole

$U = -\vec{M}.\vec{B} \Rightarrow U = -MB\cos\theta$

At θ = 0, τ = 0, $U = -MB$ (Stable equilibrium).

At θ = 180°, τ = 0, $U = +MB$ (Unstable equilibrium).

(c) Work done in Rotating a dipole

$W_{ext} = \Delta U = U_f - U_i$

$\Rightarrow W_{ext} = [-MB\cos\theta_f - (MB\cos\theta_i)]$

$\Rightarrow W_{ext} = MB(\cos\theta_i - \cos\theta_f)$

Field due to a Bar Magnet

Field at an Axial Line of Bar Magnet (End on position)

The field due to a bar magnet at an axial point d distance away from the centre of the magnet, is given by

$$B = \left(\frac{\mu_o}{4\pi}\right)\frac{(4m)ld}{(d^2 - l^2)^2} \quad \text{If } l^2 << d^2,\ B = \left(\frac{\mu_o}{4\pi}\right)\frac{2M}{d^3}$$

At a Point on Equatorial Line (Broad side on position)

If the distance of the point from the centre of the magnet along the equatorial line is d, the field is given by

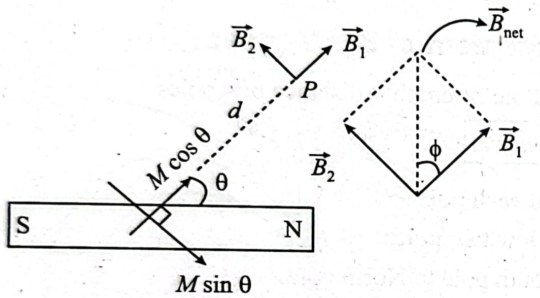
$$B = \frac{\mu_o}{4\pi}\frac{2ml}{(d^2 + l^2)^{3/2}}$$

If $l^2 << d^2$, short magnet

$$B = \frac{\mu_o}{4\pi}\left(\frac{M}{d^3}\right),\ M = \text{Magnetic moment}$$

The ratio of field at axial point and equatorial point at the same distance from the centre is 2.

At a point which makes angle θ with Bar Magnet axis:



$$\vec{B_1} = \frac{\mu_0}{4\pi}\frac{2M\cos\theta}{d^3},\quad \vec{B_2} = \frac{\mu_0}{4\pi}\frac{M\sin\theta}{d^3}$$

$$B_{net} = \sqrt{B_1^2 + B_2^2}. \quad \text{and } \tan\phi = \frac{B_2}{B_1} = \frac{\tan\theta}{2}$$

Force Between Two Small Magnets

When magnets are placed in end-on-position with respect to each other and their centers are x distance apart, the force exerted is equal to $F = \frac{\mu_0}{4\pi}\frac{6MM'}{x^4}$. As force acts along the same line, so couple is zero.

When magnets are at right angles to each other i.e. in broad side-on-position and at a distance of y, the total force exerted is $F = \frac{\mu_0}{4\pi}\frac{3MM'}{y^4}$.

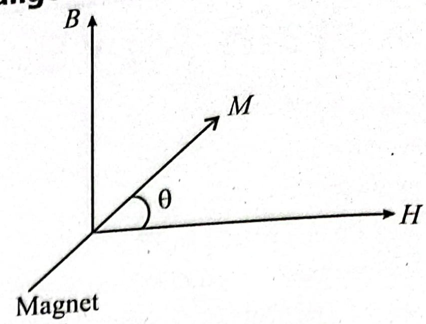
TANGENT LAW

When a magnet is suspended in a region having two mutually perpendicular field of intensities B and H, the magnet comes to rest position making an angle θ with the direction of H such that

$B = H\tan\theta$

This is known as tangent law.

Proof of Tangent Law



Torque due to $H\ (\tau_H) = MH\sin\theta$

Torque due to $B\ (\tau_B) = MB\sin(90 - \theta)$

$= MB\cos\theta$

Under rotational equilibrium,

$\tau_B = \tau_H$

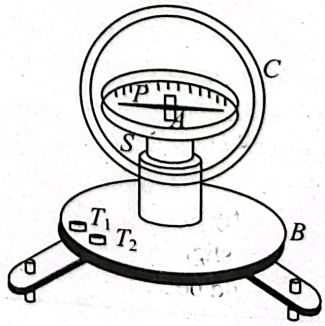
$MB\cos\theta = MH\sin\theta$

$\therefore B = H\tan\theta$

Tangent Galvanometer

Tangent galvanometer is an instrument to measure an electric current. The essential parts are a vertical circular coil C of conducting wire and a small compass needle A pivoted at the center of the coil. The coil C together with its frame is fixed to a horizontal base B provided with leveling screws. Terminals T_1 and T_2 connected to the coil are provided on this base for connecting the galvanometer to an external circuit. An aluminum pointer P is rigidly attached with the compass needle and perpendicular to it. The compass needle together with the pointer can rotate freely on horizontal plane. The ends of the pointer move over a graduated, horizontal circular scale. The graduation are marked from 0° to 90° in each quadrant.

The scale, the pointer and the compass needle are enclosed in a closed cylindrical box which is placed with its center coinciding with the center of the coil. The box can also be rotated about the vertical axis. The upper surface of the box is made of glass so that the things inside it are visible. To avoid the errors due to parallax, a plane mirror is fixed at the lower surface of the box. While noting the reading of the pointer, the eye should be properly positioned so that the image of the pointer is just below the pointer.



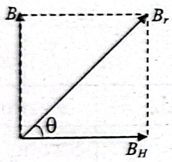
When there is no current through the galvanometer, the compass needle is in magnetic north-south direction. To measure a current with the tangent galvanometer, the base is rotated in such a way that the plane of the coil is parallel to the compass needle. The plane then coincides with the magnetic meridian. The box containing the needle is rotated so that the aluminum pointer reads 0-0 on the scale.

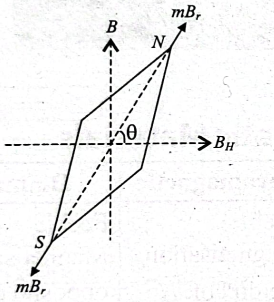
The current to be measured is passed through the coil. The current through the coil produces a magnetic field at the center and the compass needle deflects under its action. The pointer deflects through the same angle and the deflection of both the ends are read from the horizontal scale. The average of these two is calculated.

Suppose the current through the coil is I, the radius of the coil is r and the number of turns in it is N. The magnetic field produced at the center is

$$B = \frac{\mu_0 NI}{2r} \quad \text{...(i)}$$

This field is perpendicular to the plane of the coil. This direction is horizontal and perpendicular to the magnetic meridian and hence to the horizontal component B_H of the earth's magnetic field. The resultant horizontal magnetic field is $B_r = \sqrt{B^2 + B_H^2}$ in a direction making an angle θ with B_H, where $\tan\theta = B/B_H$ ...(ii)





If m be the pole strength of the needle, the force on the north pole of the needle is mB_r along B_r and on the south pole is mB_r, opposite to B_r. The needle will stay in equilibrium when its length is parallel to B_r, because then no torque is produced by the two forces. Thus, the deflection of the needle from its original position is θ as given by (ii). Using (i) and (ii),

$$B_H \tan\theta = \frac{\mu_0 NI}{2r} \text{ or } I = \frac{2rB_H}{\mu_0 N}\tan\theta \text{ or } \quad I = K\tan\theta$$

where $K = \dfrac{2rB_H}{\mu_0 N}$ is a constant for the given galvanometer at a given place. This constant is called the reduction factor of the galvanometer. The reduction factor may be obtained by passing a known current i through the galvanometer, measuring θ and then using above equation.

The equation (i) is strictly valid only at the center of the coil. The poles of the needle are slightly away from the center. Thus, the length of the needle should be small as compared to the radius of the coil.

Vibration Magnetometer

It is an instrument used for comparing the intensities of earth's magnetic field at two places and the magnetic moments of two magnets. It works on the principle that a freely suspended magnet rests in direction NS parallel to the direction of field. If this magnet is slightly displaced from its equilibrium position and left, the magnet executes SHM about the direction of field as its mean position and the time periods of vibration of the magnet is given by

$$T = 2\pi\sqrt{I / MH}$$

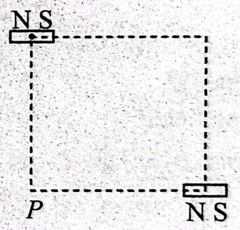
where I is the moment of inertia of the bar magnet, M is the magnetic moment of the magnet and H is intensity of uniform magnetic field (Usually, it is horizontal component of earth's magnetic field).

The ratio of horizontal components of earth's field at the two places (H_1 and H_2 respectively) if the same magnet has time period T_1 and T_2 is given by

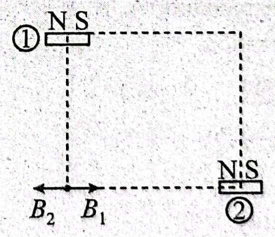
$$\frac{H_2}{H_1} = \frac{T_1^2}{T_2^2}$$

Train Your Brain

Example 6: Two short bar magnets of magnetic moment 1000 Am^2 each are placed as shown at the corners of a square of side 10cm. The net magnetic field at P is



Sol.



As B_1 and B_2 are opposite,

$\therefore\ B_{net} = B_2 - B_1$

$$= \frac{\mu_0}{4\pi}\frac{2M}{r^3} - \frac{\mu_0}{4\pi}\frac{M}{r^3} = \frac{\mu_0}{4\pi}\frac{M}{r^3}$$

$$= 10^{-7} \times \frac{1000}{\left(10^{-1}\right)^3} = 10^{-1}$$

$B_{net} = 0.1$ T

Example 7: A magnet of magnetic moment $4M$ is cut parallel to its length in such a way that the ratio of masses of two portion is 1:3. Now the two portions are tied together over each other keeping their opposite poles, together. What is the new time period of arrangement if original time period was T.

Sol. When the magnet is cut parallel to length, then magnetic moment will also be in the ratio of 1 : 3.

$\therefore \frac{M_1}{M_2} = \frac{1}{3}$. Hence $M_1 = M$ and $M_2 = 3M$

Since opposite poles are kept together.

$M_{net} = M_2 - M_1 = 2M$

We know that $T \propto \frac{1}{\sqrt{M}}$

So, $\frac{T'}{T} = \frac{\sqrt{4M}}{\sqrt{2M}} = \sqrt{2} \quad T' = \sqrt{2}T$

Concept Application

11. A bar magnet is in equilibrium under the effect of two magnetic fields which makes 60° angle with each other. Magnitude of one of the field is 7.3×10^{-4} T and a bar magnet makes an angle of 15° with the other field then value of this field is

(*a*) 2×10^{-3} T

(*b*) 4×10^{-3} T

(*c*) 2×10^{-4} T

(*d*) 4×10^{-4} T

12. The intensity of magnetic field due to an isolated pole of strength m_p at a point distant r from it will be (proportional to)

(*a*) m_p/r^2 (*b*) $m_p r^2$

(*c*) r^2/m_p (*d*) m_p/r

Short Notes

Important terms

(*a*) Magnetic field – Total no. of lines of Magnetic force per unit area

(*b*) Magnetizing field

$$\vec{H} = \frac{\vec{B}}{\mu} A/m$$

$\vec{H}$ is independent of medium

(*c*) Intensity of magnetization

$$I = \frac{\text{Magnetic Moment}}{\text{Volume}}$$

$$\Rightarrow I = \frac{M}{V}$$

(*d*) Magnetic susceptibility,

$$\chi = \frac{I}{H}$$

(*e*) Magnetic permeability: The measure of the degree to which the lines of force can penetrate or permeate the medium

μ = permeability of medium

μ_0 = permeability of free space.

$$\boxed{|\vec{B}| = \mu_0 H + \mu_0 I = \mu H}$$

Relative Permeability.

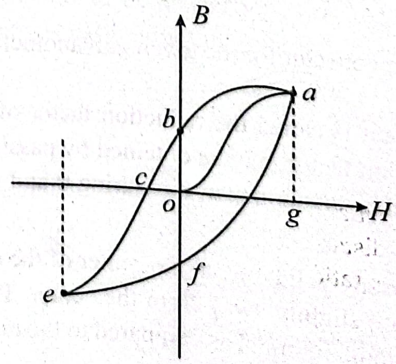
$$\mu_r = \frac{\mu}{\mu_0} = 1 + \chi$$

Magnetic Materials

Paramagnetic	Diamagnetic	Ferromagnetic
Feeble Magnetisation the dir^n of $\vec{H}$	Feeble Magnetisation opposite of $\vec{H}$	Strong Magnetisation along $\vec{H}$
$0 < \chi < 1$	$-1 \le \chi < 0$	$\chi > 100$
$\mu_r > 1$	$0 < \mu_r < 1$	$\mu_r >> 1$
$\chi \propto \frac{1}{T}$	χ is Independent of T	$\chi = \frac{C}{T - T_C}$

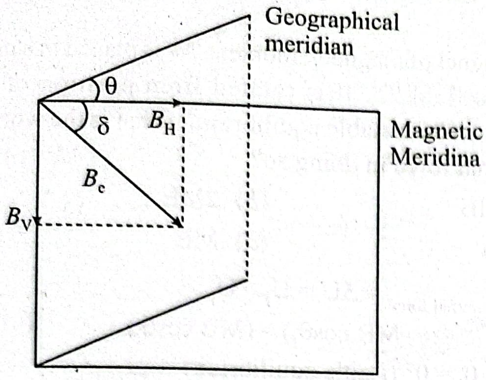
Here $T_C \rightarrow$ Curie temperature (above which a ferromagnetic material becomes paramagnetic.)

Hysteresis loop



- Retentivity = ob
- Coercivity = oc
- Area of loop = energy loss per unit volume per crcle.

Components of Earth's magnetic field



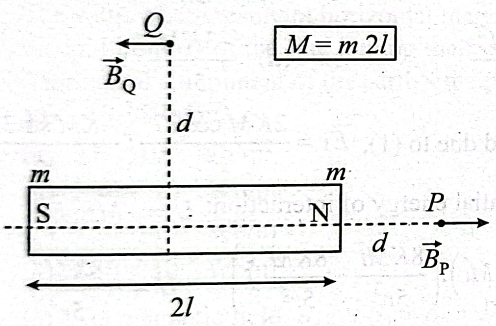
θ = Angle of declination (Angle between G.M and M.M)

δ = Angle of dip.

- $\tan\delta = \dfrac{B_V}{B_H}$
- $B_e = \dfrac{B_H}{\cos\delta}$
- $B_e = \sqrt{B_V^2 + B_H^2}$

Bar Magnet

(*a*) Magnetic field due to bar magnet.



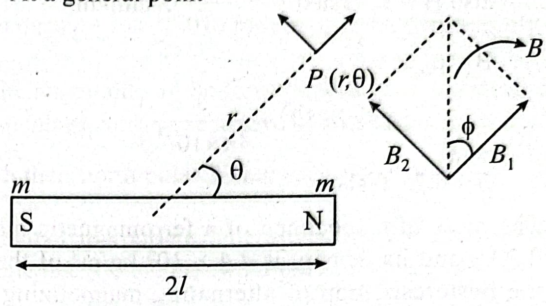
(i) $B_P = \left(\dfrac{\mu_0}{4\pi}\right)\dfrac{(4md)l}{\left(d^2 - l^2\right)^2} = \dfrac{\mu_0}{4\pi}\dfrac{2Md}{(d^2 - l^2)^2}$

If $l^2 << d^2 \Rightarrow$; $B_P = \dfrac{\mu_0}{4\pi}\dfrac{2M}{d^3}$

(ii) $B_Q = \dfrac{\mu_0}{4\pi}\dfrac{2ml}{\left(d^2 + l^2\right)^{3/2}} = \dfrac{\mu_0}{4\pi}\dfrac{M}{(d^2 + l^2)^{3/2}}$

If $l^2 << d^2$; $B_Q = \dfrac{\mu_0}{4\pi}\dfrac{M}{d^3}$

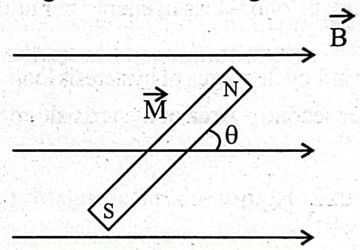
(iii) At a general point



$B = \frac{\mu_0}{4M}\cdot\frac{M}{r^3}\sqrt{1 + 3\cos^2\theta}$

$\tan\phi = \frac{\tan\theta}{2}$.

(*b*) Bar magnet in uniform magnetic field.



(i) Torque on bar magnet $\vec{\tau} = \vec{M} \times \vec{B}$

(ii) Potential energy $U = -\vec{M}.\vec{B}$

(iii) Work done in rotating the bar magnet

$W_{ext} = MB\left(\cos\theta_i - \cos\theta_f\right)$

(iv) Time period of oscillations

$T = 2\pi\sqrt{\dfrac{I}{MB}}$

$I \to$ Moment of inertia of bar magnet

Solved Examples

1. There a two points A and B on the extended axis of a short bar magnet. Their distances from the nearest pole are x and $2x$ respectively. The ratio of magnetic fields at points A and B will be

(*a*) 8 : 1 (*b*) 4 : 1

(*c*) 4 : 1 (*d*) 1 : 8

Sol. (*a*) $B = \dfrac{\mu_0}{4\pi}\dfrac{2M}{r^3}$ $\therefore B \times \dfrac{1}{r^3}$

$\therefore \dfrac{B_A}{B_B} = \dfrac{r_B^3}{r_A^3} = \dfrac{(2x)^3}{x^3} = 8$

2. A magnetic material of volume 50 cm^3 is placed in magnetic field of intensity 5 Oersted. The magnetic moment produced due to it is 10 Am^2. The value of magnetic induction will be

(a) 0.025 (b) 0.25
(c) 2.5 (d) 0.0025

Sol. (b) $I = \frac{M}{V} = \frac{10\text{Am}^2}{50\times10^{-6}\text{m}^3} = 2\times10^5$ amp/m

also H = 5 oersted = $\frac{5}{4\pi\times10^{-3}}$ amp/m

$\therefore$ B = $\mu_0 (I + H)$

$= 4\pi \times 10^{-7}\left(2\times10^5 + \frac{5}{4\pi\times10^{-3}}\right)$

$B = 0.25$ Tesla.

3. The mass of a specimen of a ferromagnetic material is 0.2 kg and its density is 4.4 × 10^3 kg/m^3 of the area of the hysteresis loop of alternating magnetizing field of frequency 50 Hz is 2.2 in MKS units then the hysteresis loss per second will be

(a) 0.2 × 10^{-5} Joule (b) 2 × 10^{-5} Joule
(c) 0.5 × 10^{-3} Joule (d) 5 × 10^{-3} Joule

Sol. (d) Area of hysteresis loop = loss in energy per unit volume per cycle

$\therefore$ loss of energy in 1 cycle = Area of hysteresis loop × volume

Hence loss per second = Area of hysterisisloop ×volume × frequeny

$= 2.2\times\left(\frac{0.2}{4.4\times10^3}\right)\times50$

= 5 × 10^{-3} Joule

4. A magnetizing field of 2 × 10^3 amp/m produces a magnetic flux density of 8π Tesla in an iron rod. The relative permeability of the rod will be

(a) 10^2 (b) 10^0
(c) 10^4 (d) 10^1

Sol. (c) $\mu_r = \frac{\mu}{\mu_0}$ and $\mu = \frac{B}{H}$

$\therefore \mu_r = \frac{B}{H\mu_0} = \frac{8\pi}{2\times10^3\times4\pi\times10^{-7}} = 10^4$

5. A bar magnet has coercivity of 50 A/m. In order to demagnetize the bar magnet it is placed inside a long solenoid with 20 turns per cm. Then the current that must flow through solenoid is

(a) 5 × 10^{-3} A (b) 2.5 × 10^2 A
(c) 5 × 10^2 A (d) 2.5 × 10^{-3} A

Sol. (a) $B = \mu_0 n I$ also $B = \mu_0 H$

$\therefore H = nI$

50 = (20 × 10^2) × I

or I = 5 × 10^{-3} A

6. Three magnets of equal length have area of cross section in the ratio 1:4:9. When placed in same magnetic field the ratio of time period will be

(a) 1:16:81 (b) 1:2:3
(c) 1:1:1 (d) 3:2:1

Sol. Pole strength (m) α Area of cross section

$\therefore$ Magnetic moment (m) α m, also I α Area, then time period (T) α A^0

7. A bar magnet of magnetic moment 'M' is placed in a uniform magnetic field 'B'. It is rotated from position of stable equilibrium to unstable equilibrium. What is the work done by external force in doing so?

(a) –2MB (b) 2MB
(c) zero (d) MB

Sol. (b) $W_{\text{external force}} = \Delta U = U_f - U_i$

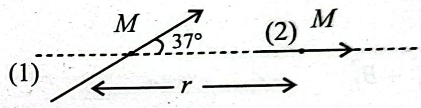
$= (-\text{MB}\cos\theta_f) - (\text{MB}\cos\theta_i)$

also $\theta_i = 0°$ (stable equilibriun)

$\theta_f = 180°$ (unstable equilibrium)

$\therefore W_{\text{external force}} = 2\text{MB}$

8. Two idential short bar magnets of magnitc moment 'M' are palced as shown in figure. The energy of intenaction of two dipoles is



(a) $\frac{8KM^2}{5r^3}$ (b) $\frac{-8KM^2}{5r^3}$

(c) $\frac{3KM^2}{5r^3}$ (d) $\frac{-3KM^2}{5r^3}$

Sol. (b) Fieled due to (1), $\vec{E}_1 = \frac{2KM\cos37°}{r^3}\hat{i} - \frac{KM\sin37°}{r^3}\hat{j}$

$\therefore$ Potential energy of interaction: $U = -\vec{M}_2\cdot\vec{E}_1$

$= -(M\hat{i}).\left(\frac{8KM\hat{i}}{5r^3} - \frac{8KM}{5r^3}\hat{j}\right)$ $U = -\frac{8KM^2}{5r^3}$

9. A student mistakenly sets the dip circle in a plane making 30° angle with magnetic meridian and measures the dip angle at that place as 45°. The correct value of dip angle at that place is

(a) $\tan^{-1}(\sqrt{3})$ (b) $\tan^{-1}\left(\frac{1}{\sqrt{3}}\right)$

(c) $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$ (d) $\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$

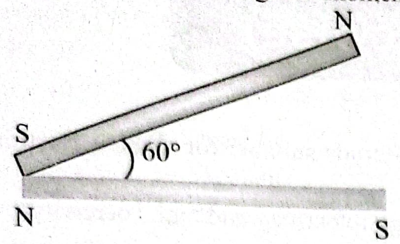
Sol. (b) $\tan\delta' = \frac{\tan\delta}{\cos\theta}$

$\Rightarrow \tan\delta = \tan\delta'\cos\theta$

$= \tan 45° \cos 30° = 1\times\frac{\sqrt{3}}{2}$

Hence $\tan\delta = \frac{\sqrt{3}}{2} \Rightarrow \delta = \tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$

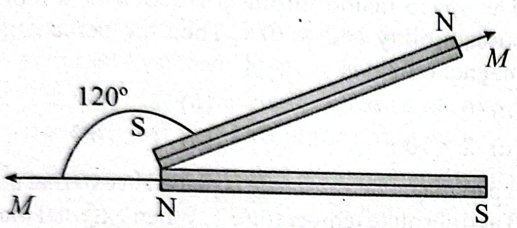
10. Two bar magnets of equal magnetic moments 'M' are placed as shown in figure. Find the net magnetic moment of the system.



(*a*) M (*b*) $\sqrt{3}M$

(*c*) $\frac{M}{2}$ (*d*) $\frac{\sqrt{3}M}{2}$

Sol. (*a*)



$\therefore M_{net} = \sqrt{M^2 + M^2 + 2MM\cos 120°}$

Hence $M_{net} = M$

11. Two short bar magnets of length 1cm each have magnetic moments 1.20 Am^2 and 1.00 Am^2, respectively. They are placed on a horizontal table parallel to each other with their N poles pointing towards the South. They have a common magnetic equator and are separated by a distance of 20.0 cm. The value of the resultant horizontal magnetic induction at the mid-point O of the line joining their centres is close to (Horizontal component of the earth's magnetic induction is 3.6×10^{-5} Wb/m^2)

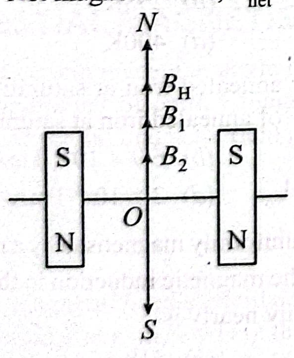
(*a*) 3.6×10^{-5} Wb/m^2

(*b*) 2.56×10^{-4} Wb/m^2

(*c*) 3.50×10^{-5} Wb/m^2

(*d*) 5.80×10^{-4} Wb/m^2

Sol. (*b*) Net magnetic field, $B_{net} = B_1 + B_2 + B_H$



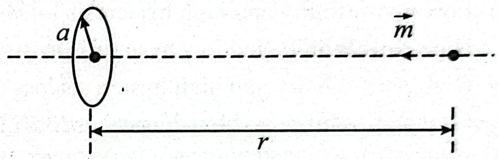
$$B_{net} = \frac{\mu_0}{4\pi}\frac{(M_1 + M_2)}{r^3} + B_H = \frac{10^{-7}(1.2+1)}{(0.1)^3} + 3.6\times10^{-5}$$

$= 2.56 \times 10^{-4}$ Wb/m^2

Paragraph for Questions 12 to 13

A special metal S conducts electricity without any resistance. A closed wire loop made of S does not allow any change in flux through itself by inducing a suitable current to generate a compensating flux. The induced current in the loop cannot decay due to its zero resistance. This current gives rise to a magnetic moment which in turn repels the source of magnetic field or flux. Consider such a loop of radius a with its center at the origin. A magnetic dipole of moment m is brought along the axis of this loop from infinity to a point at distance $r(\gg a)$ from the center of the loop with its north pole always facing the loop as shown in the figure below.

The magnitude or magnetic field of a dipole m, at a point on its axis at distance r is $\frac{\mu_0}{2\pi}\frac{m}{r^3}$, where μ_0 is the permeability of free space. The magnitude of the force between two magnetic dipoles with moments m_1 and m_2, separated by a distance r on the common axis, with their north poles facing each other is $\frac{km_1m_2}{r^4}$, where k is a constant of appropriate dimensions. The direction of this force is along the line joining the two dipoles.



12. When the dipole m is placed at a distance r from the center of the loop (as shown in the figure), the current induced in the loop will be proportional to

(*a*) $\frac{m}{r^3}$ (*b*) $\frac{m^2}{r^2}$ (*c*) $\frac{m}{r^2}$ (*d*) $\frac{m^2}{r}$

Sol. (*a*) Magnetic flux due to dipole through ring $= \frac{\mu_0}{2\pi}\times\frac{m}{r^3}\times\pi a^2$

For net magnetic flux through the loop to be zero,
Magnetic flux due to dipole = magnetic flux due to induced current

$$\Rightarrow \frac{\mu_0}{2\pi}\times\pi a^2\times\frac{m}{r^3} = I\times\pi a^2\times\frac{k}{a},$$

where k is proportionality constant $\Rightarrow \propto \frac{m}{r^3}$

13. The work done in bringing the dipole from infinity to a distance r from the center of the loop by the given process is proportional to

(*a*) $\frac{m}{r^5}$ (*b*) $\frac{m^2}{r^5}$ (*c*) $\frac{m^2}{r^6}$ (*d*) $\frac{m^2}{r^7}$

Sol. (*c*) $F = \frac{km_1m_2}{r^4} = k\left(I\pi a^2\right)\left(\frac{m}{r^4}\right)$

$F = C\frac{m^2}{r^7}$ where C is a constant obtained by substituting the value fo I from Q.14

$|W| = \int_{\infty}^{r} Fdr = Cm^2\int_{\infty}^{r}\frac{dr}{r^7} = \frac{C'm^2}{r^6}$ where C' is a constant

$|W| \propto \frac{m^2}{r^6}$

Exercise-1 (Topicwise)

MAGNETISATION, MAGNETIC INTENSITY AND MAGNETIC PROPERTIES OF MATERIAL

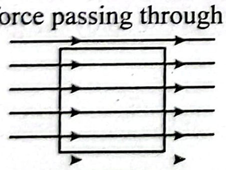
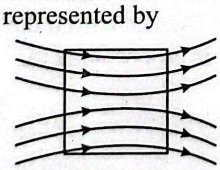
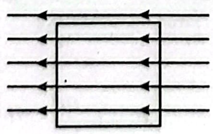
1. If a piece of metal was thought to be a magnet, which one of the following observations would offer conclusive evidence?
   (*a*) It repels a known magnet
   (*b*) It attracts a steel screw driver
   (*c*) It attracts a known magnet
   (*d*) None of the above

2. Ferromagnetic materials used in a transformer must have
   (*a*) Low permeability and high hysteresis loss
   (*b*) High permeability and low hysteresis loss
   (*c*) High permeability and high hysteresis loss
   (*d*) Low permeability and low hysteresis loss

3. If a diamagnetic substance is brought near the north or the south pole of a bar magnet, it is
   (*a*) Repelled by the north pole and attracted by the south pole
   (*b*) Attracted by the north pole and repelled by the south pole
   (*c*) Attracted by both the poles
   (*d*) Repelled by both the poles

4. Curie temperature is that above which a
   (*a*) Paramagnetic material becomes ferromagnetic material
   (*b*) Ferromagnetic material becomes diamagnetic material
   (*c*) Ferromagnetic material becomes paramagnetic material
   (*d*) Paramagnetic material becomes diamagnetic material

5. A uniform magnetic field, parallel to the plane of the paper, existed in space initially directed from left to right. When a bar of soft iron is placed in the field parallel to it, the lines of force passing through it will represented by

(*a*) 
(*b*) 
(*c*) 
(*d*) 

6. The susceptibility of a diamagnetic substance
   (*a*) Remains constant with temperature
   (*b*) First decreases and then increases with increase of temperature
   (*c*) Increases with temperature
   (*d*) Decreases with temperature

7. The materials suitable for making electromagnets should have
   (*a*) High retentivity and high coercivity
   (*b*) Low retentivity and low coercivity
   (*c*) High retentivity and low coercivity
   (*d*) Low retentivity and high coercivity

8. The space inside toroid is filled with a material whose susceptibility is 2×10^{-2}. Then the percentage change in magnetic field is
   (*a*) 0 (*b*) 2
   (*c*) 2×10^{-2} (*d*) 1×10^{-2}

9. A paramagnetic substance is placed in external magnetic field B and absolute temperature T. When external magnetic field, is tripled and temperature is quadrupled then percentage change in magnetization is
   (*a*) $\frac{3}{4}\%$ (*b*) $\frac{4}{3}\%$
   (*c*) 25% (*d*) 75%

10. A long solenoid of air core carries $\frac{1}{\pi}$A current and has 10,000 turns per metre. If the core of solenoid is completely occupied by soft iron whose relative permeability is 1001, then change in values of H and B respectively is
    (*a*) 0, 1 (*b*) 0, 4
    (*c*) 4, 0 (*d*) 4, 1

11. The susceptibility of magnesium at 300K is 1.2×10^{-5}. At what temperature will the susceptibility be equal to 1.44×10^{-5}?
    (*a*) 260K (*b*) 255K
    (*c*) 250K (*d*) 400K

12. The susceptibility of annealed iron at saturation is 5500. Find the permeability of annealed iron at saturation?
    (*a*) 7×10^{-3} TmA^{-1} (*b*) 6.9×10^{-3} TmA^{-1}
    (*c*) 3.2×10^{-3} TmA^{-1} (*d*) 2×10^{-4} TmA^{-1}

13. A specimen of iron is uniformly magnetised by a magnetising field of 500Am^{-1}. If the magnetic induction in the specimen is 0.2, the susceptibility nearly is
    (*a*) 317.5 (*b*) 418.5
    (*c*) 217.5 (*d*) 175

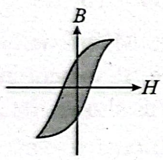
14. The magnetic susceptibility of a rod is 499. The absolute permeability of vacuum is $4\pi \times 10^{-7}$H/m. The absolute permeability of the material of the rod is
    (*a*) $\pi \times 10^{-4}$ H/m (*b*) $2\pi \times 10^{-4}$ H/m
    (*c*) $3\pi \times 10^{-4}$ H/m (*d*) $4\pi \times 10^{-4}$ H/m

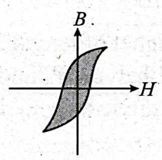
15. The magnetic moment produced in a substance of 1 g is 6×10^{-7} Am^2. If its density is 5g/cm^3, then the intensity of magnetisation (in A/m) will be:
(*a*) 8.3×10^6
(*b*) 3
(*c*) 1.2×10^{-7}
(*d*) 3×10^{-6}

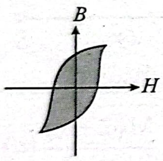
16. The hysteresis loss is caused by
(*a*) Structural non-homogeneity
(*b*) Work required for the magnetising the material
(*c*) Potential work function
(*d*) None of the above

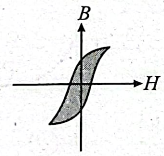
17. Which of the following statements related to hysteresis loop is incorrect?
(*a*) The curve of *B* against *H* for a ferromagnetic material is called hysteresis loop.
(*b*) The area of *B*—*H* curve is a measure of power dissipated per cycle per unit area of the specimen.
(*c*) Coercivity is a measure of the magnetic field required to destroy the residual magnetism of ferromagnetic material.
(*d*) The retentivity of a specimen is the measure of magnetic field remaining in the specimen when the magnetizing field is removed.

18. For substances hysteresis (B—H) curves are given as shown in figure. For making temporary magnet which of the following is best?

(*a*)


(*b*)


(*c*)


(*d*)


TERRESTIAL MAGNETISM

19. At certain place, the angle of dip is 60° and the horizontal component of earth's magnetic field is 0.5 oersted. The earth's total magnetic field (in oersted) is
(*a*) $\frac{1}{\sqrt{3}}$
(*b*) $\frac{1}{2}$
(*c*) 1
(*d*) $\sqrt{3}$

20. A magnetic needle oscillates in a horizontal plane with a period *T* at a place where the angle of dip is 60°. When the same needle is made to oscillate in a vertical plane coinciding with the magnetic meridian, its period will be
(*a*) $T/\sqrt{2}$
(*b*) T
(*c*) $\sqrt{2}T$
(*d*) $2T$

21. The north pole of the earth's magnet is near the geographical
(*a*) East
(*b*) West
(*c*) North
(*d*) South

22. A bar magnet is placed in the north south direction with its north pole to the north. In which direction from the centre of the bar magnet will the points of zero magnetic field lie?
(*a*) North and South
(*b*) East and West
(*c*) North East and South West
(*d*) North West and South East

23. Let ϕ_1 and ϕ_2 be the angle of dip observed in two vertical planes at right angles to each other and ϕ be the true dip then
(*a*) $\cos^2\phi = \cos^2\phi_1 + \cos^2\phi_2$
(*b*) $\sec^2\phi = \sec^2\phi_1 + \sec^2\phi_2$
(*c*) $\tan^2\phi = \tan^2\phi_1 + \tan^2\phi_2$
(*d*) $\cot^2\phi = \cot^2\phi_1 + \cot^2\phi_2$

24. In the magnetic meridian of a certain place, the horizontal component of earth's magnetic field is 0.26 G and the dip angle is 60°. Find vertical component of earth's magnetic field.
(*a*) 0.6 G
(*b*) 0.45 G
(*c*) 0.8 G
(*d*) 0.24 G

25. If the strength of the magnetic field is increased by 21% the frequency of a magnetic needle oscillating in that field
(*a*) Increased by 10%
(*b*) Decreases by 10%
(*c*) Increases by 11%
(*d*) Decreases by 21%

26. The vertical component of earth's magnetic field at a place is $\sqrt{3}$ times the horizontal component. What is the value of angle of dip at this place?
(*a*) 60°
(*b*) 50°
(*c*) 30°
(*d*) 45°

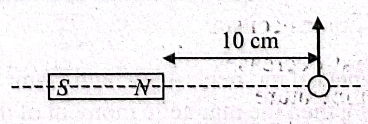
27. If reduction factor of a tangent galvanometer is 900 mA, then the current through it to produce a deflection of 45° is:
(*a*) 600 mA
(*b*) 700 mA
(*c*) 750 mA
(*d*) 900 mA

28. The earth's magnetic field inside an iron box as compared to that outside the box is
(*a*) Less
(*b*) More
(*c*) Zero
(*d*) Same

29. A compass needle is plaud on horizontal ground at magnetic poles of earth align in
(*a*) Horizontal direction
(*b*) Vertical direction
(*c*) In any direction
(*d*) Dipped at 45°

BAR MAGNET

30. An electron is moving with a velocity of 2×10^6 m/s in the vicinity of a 10 cm long bar magnet of pole strength 50 Am. What is the force on the electron?



(*a*) 8×10^{-16} N
(*b*) 4×10^{-16} N
(*c*) 16×10^{-16} N
(*d*) 2×10^{-16} N

31. If a bar magnet of magnetic moment 80 units be cut into two halves of equal lengths along a plane passing through the perpendicular bisector of the magnet, the magnetic moment of the each half will be

(*a*) 20 units (*b*) 460 units
(*c*) 40 units (*d*) 80 units

32. Force between two identical bar magnets whose centres are r m apart is 4.8 N when their axes are in the same line. If separation is increased to 2r, the force between them is reduced to

(*a*) 2.4 N (*b*) 0.6 N
(*c*) 1.2 N (*d*) 0.3 N

33. A short bar magnet produces magnetic fields of equal induction at two points, one on the axial line and the other on the equatorial line. Then the ratio of their distances is

(*a*) $1 : 2^{1/3}$ (*b*) $1 : 2$
(*c*) $2^{1/3} : 1$ (*d*) $1 : 8$

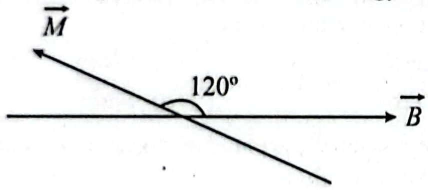
34. A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is

(*a*) 12 J (*b*) 6 J (*c*) 2 J (*d*) 0.6 J

35. Find the magnetic field due to a dipole of magnetic moment 1.2 Am^2 at a point 1m away from it in a direction making an angle of 60° with the dipole-axis.

(*a*) $1.6 \times 10^{-7}\,T$ (*b*) $3.2 \times 10^{-7}\,T$
(*c*) $1.6 \times 10^{-8}\,T$ (*d*) $0.8 \times 10^{-7}\,T$

36. A magnet of magnetic dipole moment M is released in a uniform magnetic field of induction B from the position shown in the figure. Find its kinetic energy at $\theta = 90°$.



(*a*) MB (*b*) 0 (*c*) $MB/2$ (*d*) 2 MB

37. A bar magnet of magnetic moment M_1 is axially cut into two equal parts. If these two pieces are arranged perpendicular to each other, the resultant magnetic moment is M_2. Then the value of $\frac{M_1}{M_2}$ is

(*a*) $\frac{1}{2\sqrt{2}}$ (*b*) 1 (*c*) $\frac{1}{\sqrt{2}}$ (*d*) $\sqrt{2}$

38. Two magnets of moments 4Am^2 and 3Am^2 are joined to form a cross (+), then the magnetic moment of the combination is

(*a*) 4 Am^2 (*b*) 1 Am^2
(*c*) 7 Am^2 (*d*) 5 Am^2

39. A bar magnet of length 16 cm has a pole strength of 500 milliamp.m. The angle at which it should be placed to the direction of external magnetic field of induction 2.5 gauss so that it may experience a torque of $\sqrt{3} \times 10^{-5}$ Nm is

(*a*) π (*b*) $\frac{\pi}{2}$ (*c*) $\frac{\pi}{3}$ (*d*) $\frac{\pi}{6}$

40. A bar magnet of moment $M = \hat{i} + \hat{j}$ is placed in a magnetic field induction $\vec{B} = 3\hat{i} + 4\hat{j} + 4\hat{k}$. The torque acting on the magnet is

(*a*) $4\hat{i} - 4\hat{j} + \hat{k}$ (*b*) $\hat{i} + \hat{k}$
(*c*) $\hat{i} - \hat{j}$ (*d*) $\hat{i} + \hat{j} + \hat{k}$

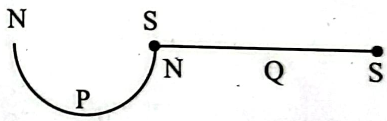
41. The work done in rotating the magnet from the direction of uniform field to the opposite direction to the field is W. The work done in rotating the magnet from the field direction to half the maximum couple position is

(*a*) 2W (*b*) $\frac{\sqrt{3}W}{2}$
(*c*) $\frac{W}{4}(2-\sqrt{3})$ (*d*) $\frac{W}{2}(1-\sqrt{3})$

42. A pole of pole strength 80 Am is placed at a point at a distance 20cm on the equitorial line from the centre of a short magnet of magnetic moment 20Am^2. The force experienced by it is

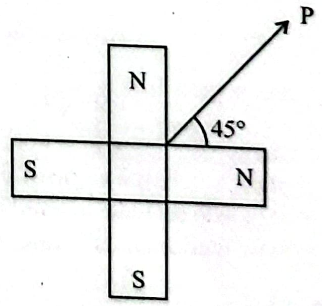
(*a*) 8×10^{-2} N (*b*) 2×10^{-2} N
(*c*) 16×10^{-2} N (*d*) 64×10^{-2} N

43. A magnet of length 2L and moment 'M' is axially cut into two equal halves 'P' and 'Q'. The piece 'P' is bent in the form of semi circle and 'Q' is attached to it as shown. Its moment is



(*a*) $\frac{M}{\pi}$ (*b*) $\frac{M}{2\pi}$ (*c*) $\frac{M(2+\pi)}{2\pi}$ (*d*) $\frac{M\pi}{(2+\pi)}$

44. Two short bar magnets of equal dipole moments 'M' each are fastened perpendicular at their centers as shown in figure. The magnitude of the magnetic field at 'P' at a distance d from their common center as shown in figure is



(*a*) $\frac{\mu_0}{4\pi}\frac{M}{d^3}$ (*b*) $\frac{\mu_0}{4\pi}\frac{2\sqrt{2}M}{d^3}$
(*c*) $\frac{\mu_0}{4\pi}\frac{2M}{d^3}$ (*d*) $\frac{\mu_0}{2\pi}\frac{M}{d^3}$

VIBRATION MAGNETOMETER

45. Two magnets are held together in a vibration magnetometer and are made to oscillate in the earth's magnetic field. With like poles together 12 oscillation per minute are made but for unlike poles together only 4 oscillations per minute executed. The ratio of their magnetic moments is:

(*a*) 3 : 1 (*b*) 1 : 3
(c) 3 : 5 (*d*) 5 : 4

46. Two short magnets having magnetic moments in the ratio 27 : 8 when placed on opposite sides of a deflection magnetometer produces no deflection. If the distance of the weaker magnet is 0.12m from the centre of deflection magnetometer the distance of the stronger magnet from the centre is:

(*a*) 0.06 m (*b*) 0.08 m
(c) 0.12 m (*d*) 0.18 m

47. A bar magnet makes 40 oscillations per minute in an oscillation magnetometer. An identical magnet is demagnetised completely and is placed over the magnet in the magnetometer. Find the time taken for 40 oscillations by this combination (Neglect any induced magnetism).

(*a*) $\sqrt{2}$ minute (*b*) $\sqrt{3}$ minute
(*c*) $\sqrt{5}$ minute (*d*) 5 minute

48. The ratio of magnetic moments of two bar magnet is 13 : 5. These magnets held together in a vibration magnetometer are allowed to oscillate in earth's magnetic field. With like poles together, 15 oscillation per minute are made. What will be the frequency of oscillation of system if unlike poles are together?

(*a*) 10 per min. (*b*) 15 per min.
(c) 12 per min. (*d*) 75/13 per min.

49. The magnet of vibration magnetometer is heated so as to reduce its magnetic moment by 36%. By doing this the periodic time of the magnetometer will:

(*a*) Increases by 36% (*b*) Increases by 25%
(c) Decreases by 25% (*d*) Decreases by 64%

Exercise-2 (Learning Plus)

1. A solenoid with total N turns having area of cross section 'A' carries 'i' current. It is made to oscillate in horizontal plane where dip angle is 60° and earth's magnetic field is B. If moment of inertia of solenoid is I, then find its time period of oscillation.

(*a*) $T = \pi\sqrt{\dfrac{8i}{NIAB}}$ (*b*) $T = 2\pi\sqrt{\dfrac{8i}{NIAB}}$

(c) $T = \pi\sqrt{\dfrac{8I}{NiAB}}$ (*d*) $T = 2\pi\sqrt{\dfrac{8I}{NiAB}}$

2. Two long parallel rails are kept closer to each other are placed on ground in magnetic meridian. The seperation between rails is 'L'. A rod carrying a constant current I and of length 'L' is placed on the rails such that rod can slide on the rails.

If angle of dip varies along the length of rails as $\delta = \dfrac{\pi x}{3L}$

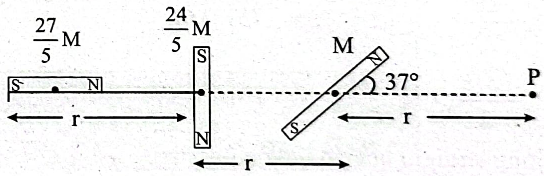
(x is distance travelled along length of rails)
then find the force experienced by rod, when rod has travelled distance equal to 'L'

(*a*) BIL (*b*) $\dfrac{BIL}{2}$ (c) $\sqrt{3}BIL$ (*d*) $\dfrac{\sqrt{3}BIL}{2}$

3. In the previous question calculate the speed of rod when it has travelled a distance 'L'. Take mass of rod as m.

(*a*) $L\sqrt{\dfrac{2BI}{\pi m}}$ (*b*) $L\sqrt{\dfrac{3BI}{\pi m}}$ (c) $\sqrt{\dfrac{BIL}{3\pi m}}$ (*d*) $\sqrt{\dfrac{BI}{2\pi m}}$

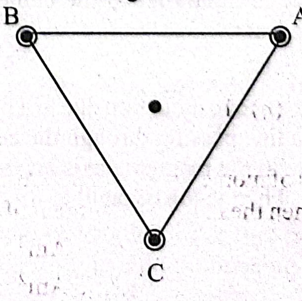
4. Three short bar magnets named 1, 2 and 3 are arranged as shown in figure. Find the magnetic field at point P $\left(K = \dfrac{\mu_0}{4\pi}\right)$



(*a*) $\dfrac{KM}{r^3}$ (*b*) $\dfrac{2KM}{r^3}$

(c) $\dfrac{3KM}{r^3}$ (*d*) $\dfrac{3KM}{5r^3}$

5. Three long wires carrying equal currents I passes from the vertices of an equilateral triangle of side 'a'. Direction of current is shown in figure. If a short dipole is placed at centre of triangle in such a way that its dipole moment M is from B to A, then the bar magnet is in

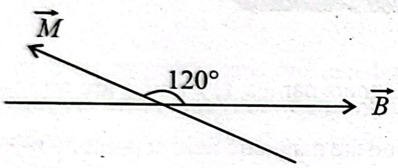


(a) Neutral equilibrium
(b) Stable equilibrium
(c) Unstable equilibrium
(d) Bar magnet is not in equilibrium

6. A magnetic needle performs 20 oscillations per minute in horizontal plane. If the angle of dip be 30°, then how many oscillations per minute will this needle perform in verlical north-south plane and in vertical east-west plane?
(a) $n_1 = 15.2, n_2 = 21.0$
(b) $n_1 = 11.5, n_2 = 15.2$
(c) $n_1 = 21.5, n_2 = 11.5$
(d) $n_1 = 21.5, n_2 = 15.2$

7. The true value of angle of dip at a place is 60°, the apparent dip in a plane inclined at an angle of 30° with magnetic meridian is
(a) $\tan^{-1}(1/2)$
(b) $\tan^{-1}2$
(c) $\tan^{-1}(2/3)$
(d) None of these

8. A magnet of magnetic dipole moment M is released in a uniform magnetic field of induction B from the position shown in the figure. Find its maximum kinetic energy during motion.



(a) $\frac{MB}{2}$ (b) MB
(c) $\frac{3MB}{2}$ (d) $2\ MB$

9. A long straight horizontal cable carries a current of 2.5 A in the direction 10° south of west to 10° north of east. The magnetic meridian of the place happens to be 10° west of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and the angle of dip is zero. A line of neutral points (Ignore the thickness of the cable)
(a) Lies above and parallel to the cable at a distance of 2.5 cm from it.
(b) Lies below and parallel to the cable at a distance of 1.5 cm from it.
(c) Lies above and parallel to the cable at a distance of 1.5 cm from it.
(d) Does not exist.

10. The resultant magnetic induction due to a magnetic dipole, at any point, on a line passing through the centre and inclined at an angle θ with the magnetic axis is perpendicular to the magnetic axis. Then value of $\tan\theta$ is
(a) 1 (b) 2
(c) $\sqrt{2}$ (d) 0.5

11. The radius of the coil of a tangent galvanometer is 0.16 m. How many turns of the wire should be wound on it if a current of 40 mA is to produce a deflection of 45° ? Given: horizontal component of earth's field is 0.36×10^{-4} T.
(a) 101 (b) 229
(c) 400 (d) 348

12. A magnetic needle lying parallel to a magnetic field requires W units of work to turn it through 60°. The torque required to maintain the needle in this position will be
(a) $\sqrt{3}W$ (b) W
(c) $\frac{\sqrt{3}}{2}W$ (d) $2W$

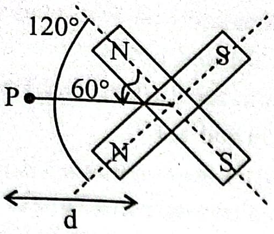
13. A bar magnet of magnetic moment 2 A-m^2 is free to rotate about a vertical axis passing through its centre. The magnet is released from rest from east-west position. Then the kinetic energy of the magnet as it takes north-south position is (horizontal component of the earth's field is 25 μT and angle of declination is zero.)
(a) 25μJ (b) 50μJ
(c) 100μJ (d) 125μJ

14. A magnet is suspended in the magnetic meridian with an untwisted wire. The upper end of wire is rotated through 180° to deflect the magnet by 30° from magnetic meridian. When this magnet is replaced by another magnet, the upper end of wire is rotated through 270° to deflect the magnet 30° from magnetic meridian. The ratio of magnetic moments of magnets is
(a) 1 : 5 (b) 1 : 8
(c) 5 : 8 (d) 8 : 5

15. A toroid has a mean radius R equal to $\frac{20}{\pi}$ cm, and a total of 400 turns of wire carrying a current of 2.0A. An aluminium ring at temperature 280 K inside the toroid provides the core. At this temperature magnetisation $\overline{M}$ of core is 4.8×10^{-2} A/m. If the temperature of the aluminium ring is raised to 320 K, what will be the magnetization?
(a) 2.4×10^{-2} A/m (b) 4.2×10^{-2} A/m
(c) 2.1×10^{-2} A/m (d) 3.4×10^{-2} A/m

16. A permanent magnet has shape of a thin disc with magnetic moment along its axis the radius of the disc is 1cm. The magnetic field due to it can be assumed to be that due to a molecular current I flowing along the rim of the disc. It $\vec{B}$ at a distance of 10 cm from its centre on the axis is 30μT, find I (approximately).
(a) 1 kA (b) 0.5 kA
(c) 2.5 kA (d) 3 kA

17. Two short bar magnets each of magnetic moment M are placed as shown in the figure. The magnetic field at the point P will be



(a) $\frac{\mu_0}{4\pi}\frac{2\sqrt{2}M}{d^3}$ towards right

(b) $\frac{\mu_0}{4\pi}\frac{2\sqrt{2}M}{d^3}$ towards left

(c) $\frac{\mu_0}{4\pi}\frac{2M}{d^3}$ towards right

(d) $\frac{\mu_0}{4\pi}\frac{2M}{d^3}$ towards left

18. A toroid is filled with liquid oxygen that has a susceptibility of 4×10^{-3}. The toroid has 2000 turns and carries a current of 15 A. Its mean radius is 20 cm, and the radius of its cross section is 0.8 cm. What is the percentage increase in B produced by the liquid oxygen?

(a) 4% (b) 0.4%
(c) 2% (d) 1.8%

19. A magnetic material of volume 30 cm^3 is placed in a magnetic field of intensity 5×10^4 A/m. The magnetic moment produced due to it is 6 amp-m^2. The value of magnetic field will be

(a) 0.314 Tesla (b) 3.14 Tesla
(c) 0.0314 Tesla (d) 3.14×10^4 Tesla

20. A ferromagnetic substance of volume 10^{-3} m^3 is placed in an alternating field of 50 Hz. Area of hysteresis curve obtained is 0.1 M.K.S. unit. The heat produced due to energy loss per second in the substance will be (Take: In hysteresis curve energy density proportional constant is 1 M.K.S. unit)

(a) 5 J (b) 5×10^{-3} cal
(c) 1.19×10^{-3} cal (d) No loss of energy

21. Two like magnetic poles of strength 10Am and 40Am are separated by a distance 30cm. The intensity of magnetic field is zero on the line joining them:

(a) At a point 10 cm from the stronger pole
(b) At a point 20 cm from the stronger pole
(c) At the mid-point
(d) At infinity

22. A certain amount of current when flowing in a properly set tangent galvanometer, produces a deflection of 45°. If the current be reduced by a factor of $\sqrt{3}$, then the deflection would:

(a) Decrease by 30° (b) Decrease by 15°
(c) Increase by 15° (d) Increase by 20°

23. A magnetised steel wire 31.4 cm long has pole strength of 0.2 Am. It is then bent in the form of a semicircle. What is the magnetic moment of the semicircle?

(a) 0.04 Am^2 (b) 0.05 Am^2
(c) 0.06 Am^2 (d) 0.07 Am^2

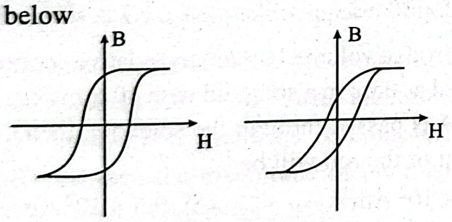
24. The time period of a freely suspended magnet is 4 sec. If it is broken in length into two equal parts and one part is suspended in the same way then its time period will be:

(a) 4 sec (b) 2 sec
(c) 0.5 sec (d) 0.25 sec

Exercise-3 (Past Year Questions)

JEE MAIN

1. Hysteresis loops for two magnetic materials A and B are given below **(2016)**



These materials are used to make magnets for electric generators, transformer core and electromagnet core. Then it is proper to use

(a) A for electromagnets and B for electric generators
(b) A for transformers and B for electric generators
(c) B for electromagnets and transformers
(d) A for electric generators and transformers

2. A magnetic needle of magnetic moment 6.7×10^{-2} Am^2 and moment of inertia 7.5×10^{-6} kg m^2 is performing simple harmonic oscillations in a magnetic field of 0.01 T. Time taken for 10 complete oscillations is: **(2017)**

(a) 6.98 s (b) 8.76 s
(c) 6.65 s (d) 8.89 s

3. A paramagnetic substance in the form of a cube with sides 1 cm has a magnetic dipole moment of 20×10^{-6} J/T when a magnetic intensity of 60×10^3 A/m is applied. Its magnetic susceptibility is **(2019)**

(a) 3.3×10^{-2} (b) 40.3×10^{-2}
(c) 2.3×10^{-2} (d) 3.3×10^{-4}

4. At some location on earth the hoizontal component of earth's magnetic field is 18×10^{-6} T. At this location, magnetic needle of length 0.12 m and pole strength 1.8 A m is suspended from its mid-point using a thread, it makes

45° angle with horizontal in equilibrium. To keep this needle horizontal, the vertical force that should be applied at one of its ends is (2019)

(a) 3.6×10^{-5} N
(b) 1.8×10^{-5} N
(c) 1.3×10^{-5} N
(d) 6.5×10^{-5} N

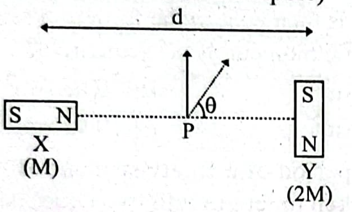
5. A bar magnet is demagnetized by inserting it inside a solenoid of length 0.2 m, 100 turns, and carrying a current of 5.2 A. The coercivity of the bar magnet is (2019)

(a) 285 A/m
(b) 2600 A/m
(c) 520 A/m
(d) 1200 A/m

6. A paramagnetic material has 10^{28} atoms/m^3. Its magnetic susceptibility at temperature 350 K is 2.8×10^{-4}. Its susceptibility at 300 K is (2019)

(a) 3.267×10^{-4}
(b) 3.672×10^{-4}
(c) 3.726×10^{-4}
(d) 2.672×10^{-4}

7. Two magnetic dipoles X and Y are placed at a separation d, with their axes perpendicular to each other. The dipole moment of Y is twice that of X. A particle of charge q is passing, through their midpoint P, at angle θ = 45° with the horizontal line, as shown in figure. What would be the magnitude of force on the particle at that instant? (d is much larger than the dimensions of the dipole) (2019)

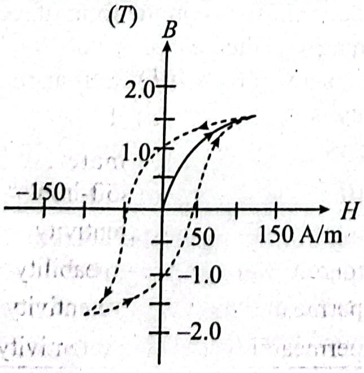


(a) $\sqrt{2}\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(d/2)^3}\times qv$
(b) $\left(\frac{\mu_0}{4\pi}\right)\frac{2M}{(d/2)^3}\times qv$
(c) $\left(\frac{\mu_0}{4\pi}\right)\frac{M}{(d/2)^3}\times qv$
(d) 0

8. A magnetic compass needle oscillates 30 times per minute at a place where the dip is 45°, and 40 times per minute where the dip is 30°. If B_1 and B_2 are respectively the total magnetic field due to the earth at the two places, then the ratio B_1/B_2 is best given by (2019)

(a) 2.2
(b) 1.8
(c) 0.7
(d) 3.6

9. The figure given experimentally measured B vs H variation in a ferromagnetic material. The retentivity, coercivity and saturation, respectively, of the material are (2020)

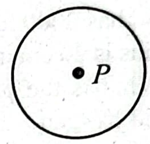


(a) 1.0 T, 50 A/m and 1.5T
(b) 150A/m, 1.0 T and 1.5T
(c) 1.5 T, 50 A/m and 1.0T
(d) 1.5T, 50A/m and 1.0 T

10. Magnetic materials used for making permanent magnets (P) and magnets in a transformer (T) have different properties of the following. Which property best matches for the type of magnet required? (2020)

(a) T : Large retentivity, small coercivity
(b) P : Large retentivity, large coercivity
(c) P : Small retentivity, large coercivity
(d) T : Large retentivity, large coercivity

11. A perfectly diamagnetic sphere has a small spherical cavity at its centre which is filled with a paramagnetic substance. The whole system is placed in a uniform magnetic field $\vec{B}$. Then the field inside the paramagnetic substance is (2020)



(a) Much larger than $|\vec{B}|$ and parallel to $\vec{B}$
(b) $\vec{B}$
(c) Much larger than $|\vec{B}|$ and opposite to $\vec{B}$
(d) Zero

12. A paramagnetic sample shows a net magnetisation of 6 A/m when it is placed in an external magnetic field of 0.4 T at a temperature of 4 K. When the sample is placed in an external magnetic field of 0.3 T at a temperature of 24 K, then the magnetisation will be (2020)

(a) 1 A/m
(b) 0.75 A/m
(c) 4 A/m
(d) 2.25 A/m

13. A small bar magnet placed with its axis at 30° with an external field of 0.06 T experiences a torque of 0.018 Nm. The minimum work required to rotate it from its stable to unstable equilibrium position is (2020)

(a) 9.2×10^{-3} J
(b) 6.4×10^{-2} J
(c) 7.2×10^{-2} J
(d) 11.7×10^{-3} J

14. An iron rod of volume 10^{-3} m^3 and relative permeability 1000 is placed as core in a solenoid with 10 turns/cm. If a current of 0.5 A is passed through the solenoid, then the magnetic moment of the rod will be (2020)

(a) 5×10^2 Am^2
(b) 0.5×10^2 Am^2
(c) 500×10^2 Am^2
(d) 50×10^2 Am^2

15. Which of the following statements are correct? (2021)

(A) Electric monopoles do not exist whereas magnetic monopoles exist.
(B) Magnetic field lines due to a solenoid at its ends and outside cannot be completely straight and confined.

(C) Magnetic field lines are completely confined within a toroid.

(D) Magnetic field lines inside a bar magnet are not parallel.

(E) $\chi = -1$ is the condition for a perfect diamagnetic material, where x is its magnetic susceptibility.

Choose the correct answer from the options given below:

(*a*) (A) and (B) only (*b*) (B) and (C) only

(*c*) (C) and (E) only (*d*) (B) and (D) only

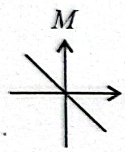
16. A solenoid of 1000 turns per metre has a core with relative permeability 500 . Insulated windings of the solenoid carry an electric current of 5 A. The magnetic flux density produced by the solenoid is:(Permeability of free space is $4\pi \times 10^{-7}$) **(2021)**

(*a*) π T (*b*) $2 \times 10^{-3}\, \pi$ T

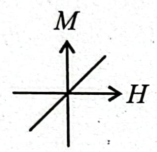
(*c*) $10^{-4}\, \pi$ T (*d*) $\frac{\pi}{5}$T

17. Following plots show magnetization (M) vs magnetising field (H) and magnetic susceptibility (χ) vs temperature (T) graph: **(2021)**

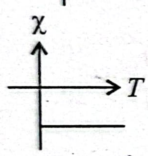
(A)



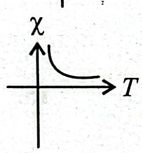
(B)



(C)



(D)



Which of the following combination will be represented by a diamagnetic material?

(*a*) (A), (C) (*b*) (A), (D)

(*c*) (B), (D) (*d*) (B), (C)

18. Choose the correct option **(2021)**

(*a*) True dip is not mathematically related to apparent dip.

(*b*) True dip is less than apparent dip.

(*c*) True dip is always greater than the apparent dip.

(*d*) True dip is always equal to apparent dip.

19. In a uniform magnetic field, the magnetic needle has a magnetic moment 9.85×10^{-2} A/m^2 and moment of inertia 5×10^{-6} kg m^2. If it performs 10 complete oscillations in 5 seconds then the magnitude of the magnetic field is ________ mT [Take π^2 as 9.85] **(2021)**

20. A bar magnet of length 14 cm is placed in the magnetic meridian with its north pole pointing towards the geographic north pole. A neutral point is obtained at a distance of 18 cm from the center of the magnet. If $B_H = 0.4$ G, the magnetic moment of the magnet is (1G = 10^{-4} T) **(2021)**

(*a*) 2.880×10^3 J T^{-1} (*b*) 2.880×10^2 J T^{-1}

(*c*) 2.880 J T^{-1} (*d*) 28.80 J T^{-1}

21. A soft ferromagnetic material is placed in an external magnetic field. The magnetic domains? **(2021)**

(*a*) Decrease in size and changes orientation

(*b*) May increase or decrease in size and change its orientation.

(*c*) Increase in size but no change in orientation

(*d*) Have no relation with external magnetic field.

22. Given below are two statements: **(2022)**

Statement-I: Susceptibilities of paramagnetic and ferromagnetic substances increase with decrease in temperature.

Statement-II: Diamagnetism is a result of orbital motions of electrons developing magnetic moments opposite to the applied magnetic field.

Choose the CORRECT answer from the options given below:-

(*a*) Both Statement-I and Statement-II are true.

(*b*) Both Statement-I and Statement-II are false.

(*c*) Statement-I is true but statement-II is false.

(*d*) Statement-I is false but Statement-II is true.

23. The space inside a straight current carrying solenoid is filled with a magnetic material having magnetic susceptibility equal to 1.2×10^{-5}. What is fractional increase in the magnetic field inside solenoid with respect to air as medium inside the solenoid? **(2022)**

(*a*) 1.2×10^{-5} (*b*) 1.2×10^{-3}

(*c*) 1.8×10^{-3} (*d*) 2.4×10^{-5}

24. At a certain place the angle of dip is 30° and the horizontal component of earth's magnetic field is 0.5 G. The earth's total magnetic field (in G), at that certain place, is: **(2022)**

(*a*) $\frac{1}{\sqrt{3}}$ (*b*) $\frac{1}{2}$ (*c*) $\sqrt{3}$ (*d*) 1

25. A magnet hung at 45° with magnetic meridian makes an angle of 60° with the horizontal. The actual value of the angle of dip is **(2022)**

(*a*) $\tan^{-1}\left(\sqrt{\frac{3}{2}}\right)$ (*b*) $\tan^{-1}\left(\sqrt{6}\right)$

(*d*) $\tan^{-1}\left(\sqrt{\frac{2}{3}}\right)$ (*d*) $\tan^{-1}\left(\sqrt{\frac{1}{2}}\right)$

26. The vertical component of the earth's magnetic field is 6×10^{-5} T at any place where the angle of dip is 37°. The earth's resultant magnetic field at that place will be

(Given $\tan 37° = \frac{3}{4}$) **(2022)**

(*a*) 8×10^{-5} T (*b*) 6×10^{-5} T

(*c*) 5×10^{-4} T (*d*) 1×10^{-4} T

27. The soft-iron is a suitable material for making an electromagnet. This is because soft-iron has: **(2022)**

(*a*) Low coercivity and high retentivity

(*b*) Low coercivity and low permeability

(*c*) High permeability and low retentivity

(*d*) High permeability and high retentivity

ANSWER KEY

CONCEPT APPLICATION

1. (b)	2. (c)	3. (a)	4. (c)	5. (b)	6. (c)	7. (c)	8. (b)	9. (d)	10. (a)
11. (a)	12. (a)								

EXERCISE-1 (TOPICWISE)

1. (a)	2. (b)	3. (d)	4. (c)	5. (b)	6. (a)	7. (b)	8. (b)	9. (c)	10. (b)
11. (c)	12. (b)	13. (a)	14. (b)	15. (b)	16. (b)	17. (b)	18. (d)	19. (c)	20. (a)
21. (d)	22. (b)	23. (d)	24. (b)	25. (a)	26. (a)	27. (d)	28. (a)	29. (c)	30. (a)
31. (c)	32. (d)	33. (c)	34. (b)	35. (a)	36. (c)	37. (d)	38. (d)	39. (c)	40. (a)
41. (c)	42. (b)	43. (c)	44. (b)	45. (d)	46. (d)	47. (a)	48. (a)	49. (b)	

EXERCISE-2 (LEARNING PLUS)

1. (c)	2. (d)	3. (b)	4. (b)	5. (b)	6. (d)	7. (b)	8. (c)	9. (c)	10. (c)
11. (b)	12. (a)	13. (b)	14. (c)	15. (b)	16. (b)	17. (d)	18. (b)	19. (a)	20. (c)
21. (b)	22. (b)	23. (a)	24. (b)						

EXERCISE-3 (PAST YEAR QUESTIONS)

JEE Main

1. (c)	2. (c)	3. (d)	4. (d)	5. (b)	6. (a)	7. (d)	8. (c)	9. (a)	10. (b)
11. (d)	12. (b)	13. (c)	14. (a)	15. (c)	16. (a)	17. (a)	18. (b)	19. [8]	20. (c)
21. (b)	22. (a)	23. (a)	24. (a)	25. (a)	26. (d)	27. (c)			